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Intelligent Automation Incorporated

Coherent distributed radar for high-resolution through-wall imaging

Progress Report 12

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Summary

In this period of performance, we are continuing to develop the radar design, software, and software for the final demonstration. We are also ordering and building the final demonstration hardware.

1.0 INTRODUCTION

In this report we discuss progress in radar design, software design, and simulations

1.1 Radar Design

We are considering options for what waveform to use for the final demonstration. Specifically, we are considering increasing the bandwidth of the synchronization signal to ~100MHz, and use it for radar also. We are also considering a more conventional chirp waveform. We are considering operation in one or more IMS bands, which would allow unlicensed operation, and higher transmit power than the unlicensed UWB. We are exploring these options trough simulations, we show initial results below.

1.2 Software design

We continue to develop the software application at the receiver. Specifically, we are integrating a prior C program that was developed to acquire DGPS signal, with a compass, so that the position of the radar antenna can be estimated with ~2cm accuracy. We have also started development on integrating this C code with another JAVA-based code that allows for display of the antenna coordinates on a Google map-like display.

1.3 Simulations

We have started simulations of the bi-static radar signal generation, reception, and processing for multiple point targets behind a barrier. We are comparing performance of a conventional small aperture, single platform UWB through wall radar, with that of a wideband (~80MHz) very large aperture radar. We detail results below.

1. UWB through-wall radar

In an ARL report [Martone, 2009], a typical through-wall imaging radar is presented. This ARL ground-based, Synchronous Impulse Reconstruction (SIR) radar system is an impulse-based, ultra-wideband (UWB) imaging radar with a bandwidth covering 300MHz to 3GHz. It employs a physical aperture of 16 receiver antennas. These antennas are equally spaced across a linear aperture that is approximately 2 m long. Two impulse transmitters are located at either end and slightly above the receive array, as illustrated in Figure 1.

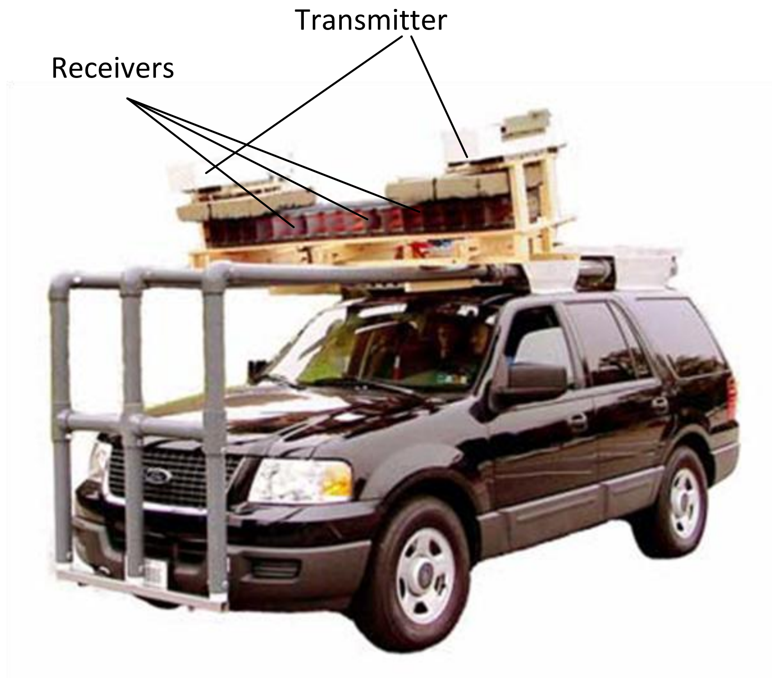

Figure 1 ARL's ground-based UWB radar: SIRE.

The transmitters fire in an alternating sequence—the left transmitter followed by the right. Each transmitter launches a sequence of low-power pulses, and reflected energy is integrated within each receive channel to achieve an acceptable signal-to-noise ratio (SNR). The SIRE radar constructs a high-resolution (0.056 m) downrange profile. This is determined by the bandwidth of the system, i.e.

$$r_R = \frac{c}{2B}$$

Simply employing the back-projection algorithm, 2D Synthetic Aperture Radar (SAR) images can be focused by coherently overlapping the 1D range profiles into the 2D imaging space. According to SAR principles, the resolution in cross-range dimension is determined by the synthetic aperture size which can be approximately estimated as

$$r_A = \frac{\lambda}{2\theta} = \frac{\lambda R}{2L}$$

where R is the range of the imaging area, L is the synthetic aperture size, and θ is the equivalent span of viewing angle.

In the case discussed in this report [Martone, 2009], the imaging area extends from approximately 10 to 35 m. Therefore, we consider $R = 20m$, which yields cross-range resolution of 0.91m. Note that the cross-range resolution is far worse than range resolution. Fortunately, in most through-wall applications, moving target indication (MTI) techniques are employed to detect moving targets behind wall. The static background clutter is cancelled out. Therefore, MTI capability is not significantly limited by the disparity of range vs. cross-range resolution. Moving targets can always be identified as long as they are separated slightly in range dimension.

2. Extended synthetic aperture

In order to improve cross-range resolution, we have to extend the synthetic aperture size. To show the improvement of cross-range resolution, we simulated SAR images of a scene of 5 point targets. As show in Figure 2, the center target is located 15m away from radar, while the other 4 targets are displaced from the center by 0.5m or 3m in either range or cross-range. Note that direct scattering from the wall is ignored in this simulation.

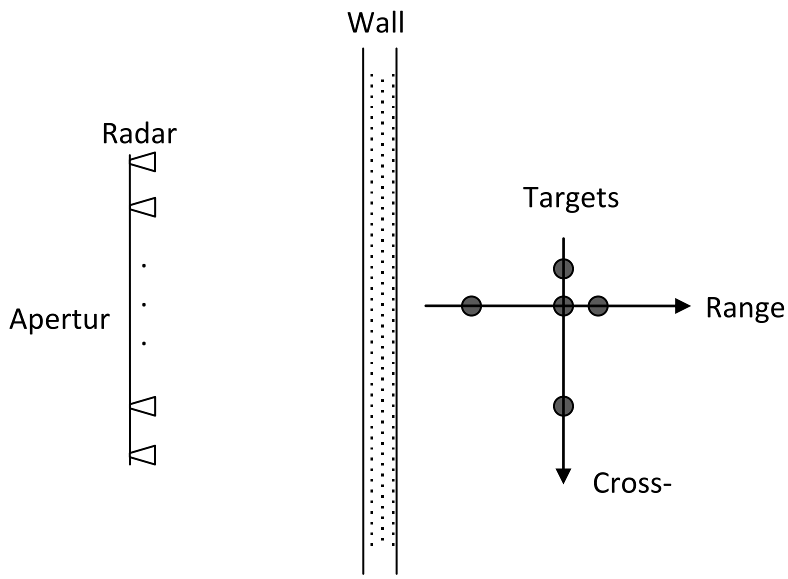

Figure 2 Through-wall SAR image simulation of point targets.

In Figure 3, SAR images of the 5 point targets are shown for the regular 2m-aperture case and an extended 8m-aperture case. Obviously, the first configuration failed to discriminate the two targets displaced by 0.5m in cross-range direction. Also notice that, with extended aperture, even the static SAR without MTI is very informative. In addition to detecting moving target, it could be used to retrieve information about the static scene behind the wall.

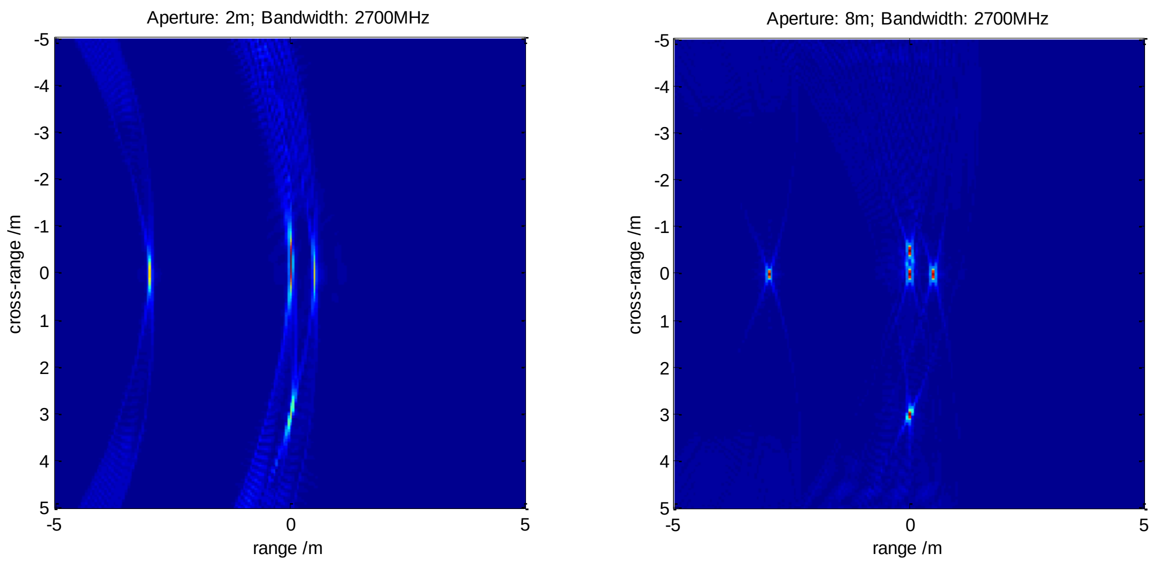

Figure 3 Simulated UWB SAR image with (left) regular aperture and (right) extended aperture.

The aperture size is mainly restricted by the platform size. It is impractical to extend the aperture up to 8m on a ground platform. If we employ a bistatic configuration, such large aperture can be easily achieved by moving a portable receiver around the wall. A static transmitter can be mounted on ground platform, while portable low-power receivers can be carried by person or car. Theoretically, there is no limit of aperture size as the receiver can be moved across as long distance as possible. In practice, the maximum valid synthetic aperture size will be limited by the maximum coherent looking angle, which is the maximum variation of looking angle without losing the coherency in scattering of the target [Ertin, E. et al. 2007].

3. Wide-aperture and narrow-band system

In practice, UWB systems have very limited transmitting power according to FCC regulations under Part 15 (unlicensed band). Exceeding 50microwatts would require the operator to obtain a FCC license before using the system. Given that an extremely wide aperture can be achieved by bistatic portable receiver, system bandwidth maybe reduced without compromising imaging and MTI performance. In that case, the system can be operated in unlicensed band with much larger transmitting power. Two immediate benefits would be longer operating range and avoidance of FCC license application for each user. Below simulation will show how the images look like with wide aperture but limited bandwidth.

The system parameters are the same except using an unlicensed band (bandwidth 80MHz) at 2.4GHz. As shown in Figure 4, with the 8m aperture, the 5 point targets appear to be smeared in range direction and the two targets located too close in range direction are not identifiable. As we further increase the aperture to 24m, we found that all targets become sharper and even the two targets which are close in range direction can now be discriminated. This result indicates that if we employ an extremely large aperture, it is possible to achieve good performance with very limited system bandwidth, in applications of both MTI and static scene imaging. However, we notice that sidelobes are much higher in narrow-band cases.

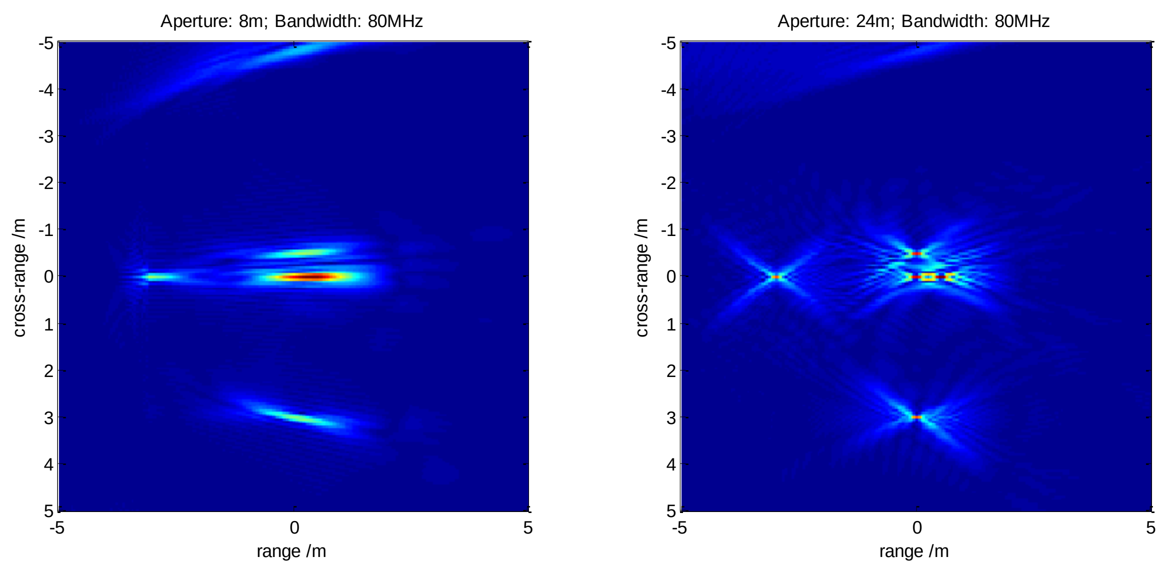

Figure 4 Simulated narrow-band SAR with large apertures.

4. Future work

In next reporting period, we will focus on specific demonstration system design such as frequency selection, link budget analysis etc. We will also perform high-fidelity simulation which incorporates accurate electromagnetic scattering models for wall and target. Meanwhile, we will also include sensitivity analysis of synchronization error, both in time and frequency (phase).

References

Martone, A. et al. (2009): Moving Target Indication for Transparent Urban Structures, ARL report ARL-TR-4809, 2009

Ertin, E. et al. (2007): GOTCHA experience report: three-dimensional SAR imaging with complete circular apertures, Proc. SPIE, Vol. 6568, 656802 (2007); doi:10.1117/12.723245